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Analysis

During the launch of Starship, a very similar phenomenon took place, as happened during the launch of the Russian N1. Engines fell out one after the other. We know about the N1 that excessive vibrations caused the failure of some engines to fail in series. My opinion is that this happened here too.

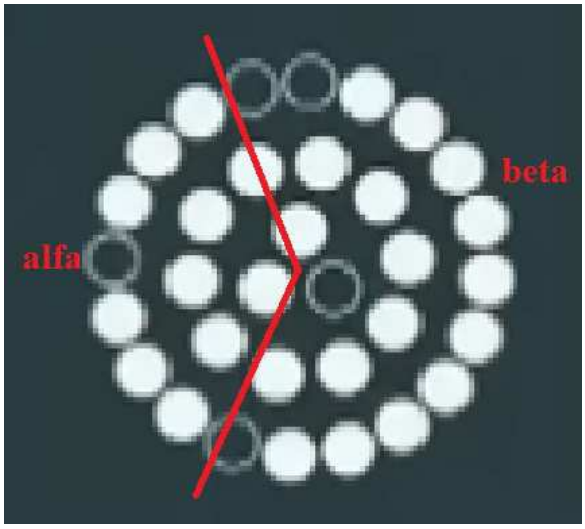
Objects with the same dynamics and characteristic frequency, arranged in a group, on a common platform, were operated and started unsynchronized. This led to a special phenomenon: spontaneous synchronization.

www.youtube.com/watch?v=T58lGKREubo

It can be observed in the video that the element that synchronized last is "hit" by the others. Such a phenomenon destroys the engines, from the group consisting of 33 elements.

The elements of the drive group provide perfect conditions for spontaneous synchronization. They are manufactured to be as uniform as possible. The engines are arranged symmetrically on a common, homogeneous platform. All the conditions are right for the spontaneously synchronizing vibration. Only as long as the actuation energy is many orders of magnitude lower for the structural strength of the metronomes in the video, the structural utilization of an engine must be increased to the extreme. There is almost certainly no reserve to withstand the extra stresses occurring at the last elements of the round-robin synchronization.

It is interesting that, while the state in the figure below was established quickly, it persisted for a relatively long time afterwards.



Another interesting fact is that the ratio of the alpha and beta angles gives approximately the ratio of the golden ratio, 1.618.

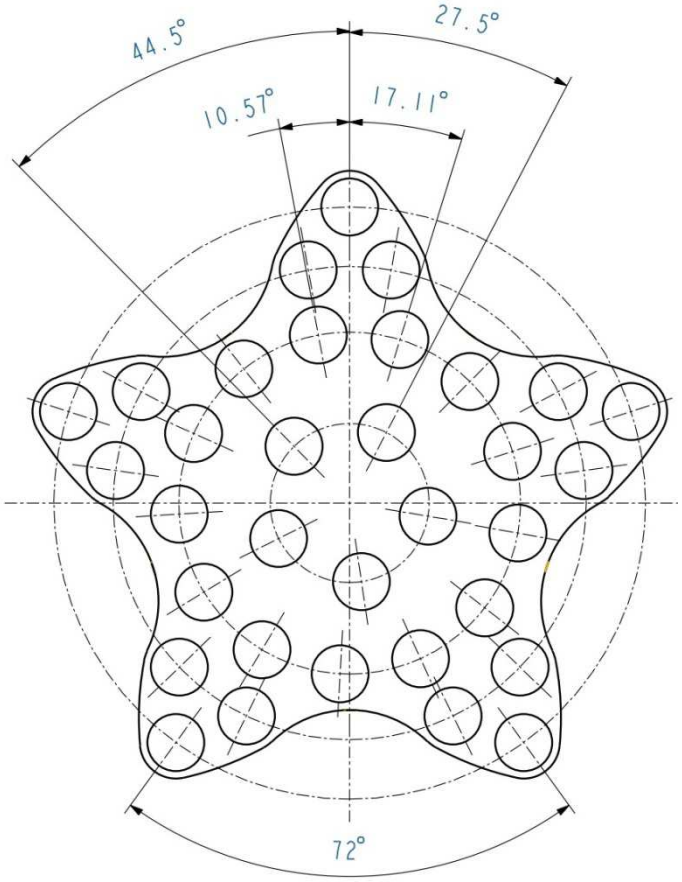
After this was formed - according to my assumption - the synchronization, which runs continuously, simultaneously, in two directions, could no longer accumulate enough energy at the meeting points, with which it would have been able to move beyond the failed units. The natural asymmetry protected the rest. This process can probably be identified from the analysis of the continuously measured vibration image and/or the sound effect. Up to the state shown in the picture, the intensity of the frequencies characteristic of the unique vibration pattern of the engines had to increase, and then it had to decrease.

I think that for such units, symmetry is particularly harmful.

In the case of the Saturn V, the five giant engines are not a large group and operated uncertainly, so they have forced ignition. In addition to the forced ignition, the independent combustion also worked, at an irregular rate and thus together they form a completely gray noise. Neither engine is threatened by a synchronization shock.

The solution is also to be found here, the gear unit must be asymmetric in as many ways as possible!

I recommend the solution shown in the figure.



44,5° / 27.5° = 17.11° / 10.57° = 1.618

I no longer dare to rely only on this ratio for the diameter ratios of the distributor circles of the gear units. Probably, the effects of the frame structure must also be considered here.

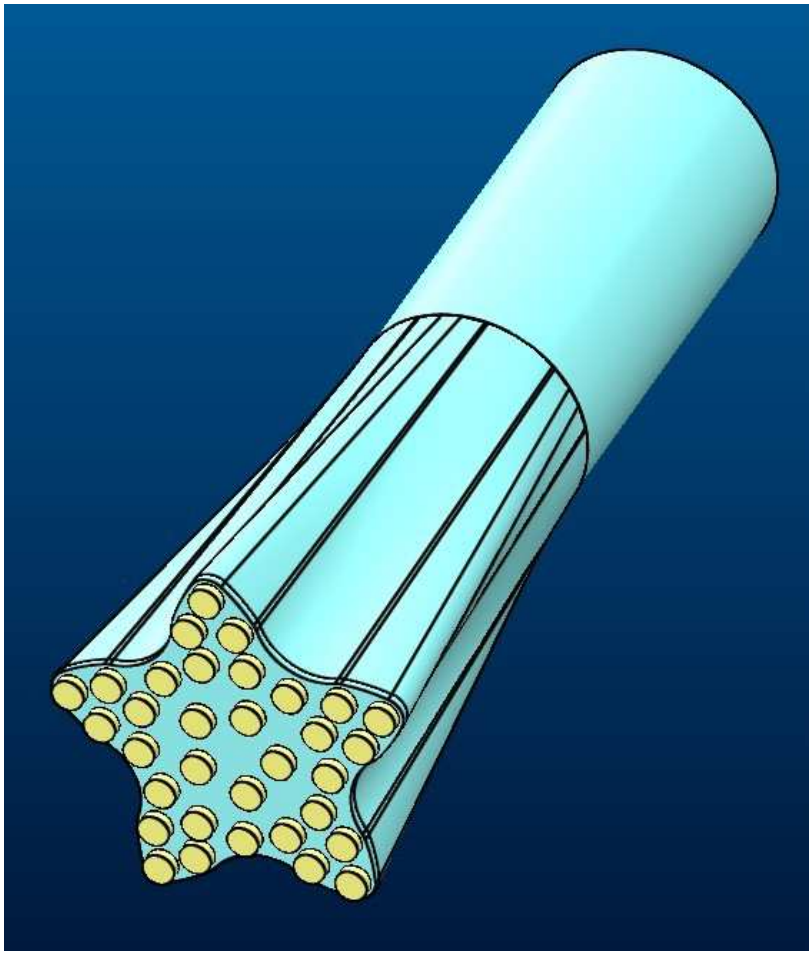
The basis of the solution is the widest possible use of the golden ratio, which was shown by the condition of the engine group during the flight.

The breaking of the circular symmetry is another characteristic, which aims to avoid locations around the engine with the same regularity.

The pentagonal arrangement gives itself, which includes the rule of the golden ratio at typical distances, and within this, the rocket engines in the circle are nowhere even in number, and their orientation angles also follow the golden ratio.

The consequence of the placement of the engines is a booster stage-like layout, with a similar flow design to the Soyuz, but not in a drop-off form. In my opinion, it is due to the shock wave formed between the acceleration stages that the otherwise circularly symmetrical engine arrangement did not lead to spontaneous synchronization problems with the Soyuz.

The design I propose is illustrated in the figure below



The slightly spread design also provides better sole stability. In addition to the same interior space, this body shape slightly reduces the height of the rocket stage.

And anyway, why shouldn't the engine image of a starship be star-shaped? ☺

I have good experience with this special numerical value. I managed to break the vibration of a resonating, long, high mass and high speed chain by distributing the supports according to the series corresponding to the golden ratio. If it is possible to freely choose the structural proportions of a dynamically loaded frame, I try to design it accordingly.

I am confident that my engineering insights can contribute to the success of the next mission!

Békéscsaba, 03. 05. 2023.

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